Fundamental Micromechanics and Materials Dynamics of Thermal Barrier Coating Systems Containing Multiple Layers

Mark L. Weaver, The University of Alabama Tuscaloosa, DMR Award #9984899

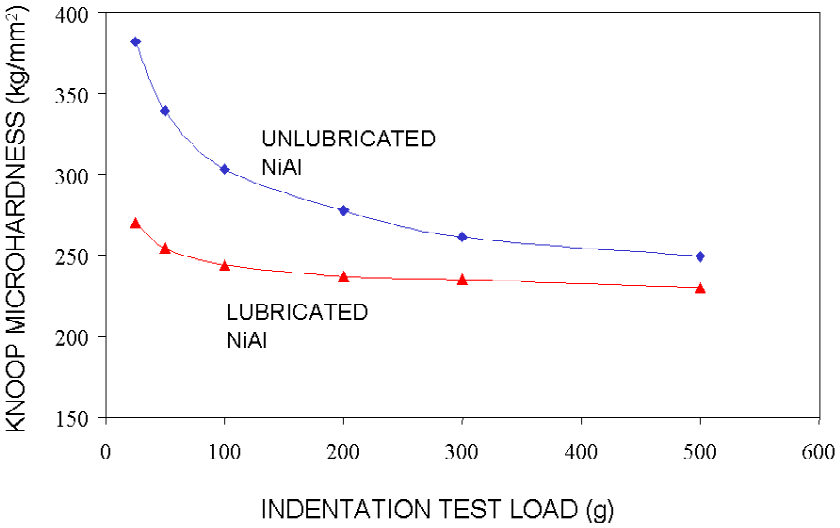
Indentation Size Effect

- Hardness tests conducted to determine mechanical properties of NiAl single crystals and NiAl bond coats applied to superalloy substrates.
- An indentation size effect (ISE) is observed in both systems.
- ISE caused by friction between the indenter and specimen surface. Lubrication of specimen removes the ISE. (Figure 1)
- An energy balance model predicts the "true" load independent microhardness for any material even in presence of ISE. (Table I)
- Important to correctly interpret the hardness results for applications to various mechanical and wear situations.

◆ ◆ ◆

M.L. Weaver, M.E. Stevenson and R.C. Bradt, "Knoop Microhardness Anisotropy and the Indentation Size Effect on the (100) of Single Crystal NiAl," in press *Materials Science and Engineering A* (2002).

B. Ning, M.E. Stevenson, M.L. Weaver and R.C. Bradt, "Apparent Indentation Size Effect in a CVD Coated Ni-Base Superalloy," submitted to *Thin Solid Films* (2002).



Load dependence of Knoop microhardness

Table I. Summary of the Energy Balance Results for the (100) of Single Crystal NiAl.

	Dry (Unlubricated)	Lubricated
Orientation	$H_{K\text{-}LIH}$ (kg/mm²)	$H_{K\text{-}LIH}$ (kg/mm²)
[011](100)	218.5 ± 5.7	220.2 ± 4.8
[021](100)	218.6 ± 5.9	220.3 ± 5.1
[010](100)	218.8 ± 6.3	220.3 ± 4.9

1. Indentation microhardness testing is non-destructive and practical way to evaluate the mechanical properties of materials at small length scales. This test method is often used in the field to assess whether or not components need to be replaced.
2. Recent years have seen the advent of nanoindentation testing as a method to determine the properties of thin films, coatings, and fine microstructures for which traditional mechanical tests (tension, compression, etc…) cannot be completed.
3. A basic understanding of the indentation process is critical to correctly interpret the hardness results for applications to various mechanical and wear situations. At low applied indentation test loads, the indentation size effect (ISE) is a common effect that creates difficulty in accurately determining the microhardness. The classical definition of the ISE is the increase in apparent hardness with a decreasing applied indentation test load.
4. In microhardness experiments conducted on oriented single crystals of NiAl, we observed that the ISE could be eliminated if the specimen surface was lubricated prior to indentation. We interpreted this as an indication that one of the major causes for the ISE is friction between the indenter and the test specimen surface.
5. For unlubricated samples, where an ISE was present, we found that the "true" load independent Knoop microhardness (LIH) of the samples could be extracted through application of an energy balance between the indenter and the test specimen.
6. The hardness of lubricated specimens was observed to be identical to the LIH predicted using the energy balance model.
7. As ISE was also observed in the NiAl coating/superalloy substrate system investigated. This ISE extended into the nanoindentation range.
8. The energy balance model, when applied to the microhardness data, successfully predicted the LIH for each part of this materials system. Application of the energy balance model to the nanoindentation data, predicted an anomalously high LIH, which we attributed this to surface contact phenomena that are still under investigation.
9. This investigation provides a means to predict the "true" hardness of a material.

Fundamental Micromechanics and Materials Dynamics of Thermal Barrier Coating Systems Containing Multiple Layers

Mark L. Weaver, The University of Alabama Tuscaloosa, DMR Award #9984899

Training

- 2 graduate students (Bo Ning and Jonathan Sullivan) have participated in research.
- 3 undergraduates have worked on the physical modeling of the morphological instabilities observed at the mid-ocean ridges.
- Student (Bo Ning) presented research at the 2002 International Conference on Metallurgical Coatings and Thin Films.

Dr Weaver demonstrating mechanical testing to summer program participants.

Outreach

- Development of lectures on the mechanical properties of thin films and coatings for required course MTE 455 – Mechanical Behavior of Materials.
- Introducing Science Faculty from HBCU's to Materials Science and Engineering– Three-week workshop to introduce to introduce mathematics and science educators from HBCU's to materials science and engineering through traditional classroom lectures, interactive laboratory activities, and site visits to national laboratories and industries involved in materials science and engineering.

Training:

•In addition to the PI, two graduate students (Bo Ning and Jonathan Sullivan) participated on this project during the 2001 – 2002 year. Their efforts resulted in two journal publications and in one presentation at a national conference. Three undergraduates, one a freshman, were also involved in research.

Outreach:

•Lectures were developed to introduce students taking the required mechanical behavior of materials course to the mechanical properties of thin films and coatings. In future years, a related laboratory exercise will be incorporated into this course.

•A three-week, NSF-sponsored summer program was conducted at The University of Alabama to introduce mathematics and science educators from HBCU's to materials science and engineering (NSF DMR-9976488 Introducing Science Faculty from Historically Black Colleges and Universities to Materials Science and Engineering).

•The objectives of this program are: (a) To provide opportunities for minority students to participate in materials science research through HBCU instructors and faculty, which will expose them to the career opportunities in materials science related disciplines; and (b) To facilitate the development of long-term research collaborations between the MRSEC faculty and faculty, instructors and students at HBCU's. This will enhance the abilities of HBCU faculty to actively participate in research activities, which in turn will aid them in conveying to their students the important roles that are played by the sciences in life. This objective facilitates objective (a).

•Currently, the workshop couples traditional classroom lectures with interactive laboratory activities and site visits to national laboratories and industries that are involved in materials science and engineering.

•Outreach activities this year will included introducing the participants to the problems associated with the deformation and durability of thin films and coatings. This year the program will reach 40 HBCU instructors.